

# Intranight Optical Variability of Radio-Quiet Weak Emission Line Quasars-II

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## ABSTRACT

This is continuation of our search for the elusive radio-quiet blazars, by carrying out a systematic programme to detect intranight optical variability (INOV) in a subset of ‘Weak-Lines-Quasars’ (WLQs) which are designated as ‘high confidence BL Lac candidates’ and are known to be radio-quiet. For 10 such RQWLQs, we present here the INOV observations taken in 16 sessions of durations  $\gtrsim 3.5$  hours each. Combining these data with our previously published INOV monitoring of RQWLQs in 13 sessions, gives a set of INOV observations of 15 RQWLQs monitored in 29 sessions each lasting more than 3.5 hours. The 29 differential light curves (DLCs), thus obtained for the 15 RQWLQs, were subjected to an statistical analysis using the F–test and the deduced INOV characteristics of the RQWLQs are compared with those published recently for several prominent AGN classes, also using the F–test. However, since the RQWLQs are generally 1–2 magnitudes fainter, a rigorous comparison has to wait for somewhat more sensitive INOV observations than those presented here. Based on our existing INOV observations, it seems that RQWLQs in our sample show a significantly higher INOV duty cycle than radio-quiet quasars and radio lobe-dominated quasars. Two sessions when we detected rather strong (blazar-like) INOV for RQWLQs are pointed out and both these RQWLQs are therefore candidates for radio-quiet BL Lacs.

**Key words:** galaxies: active – BL Lacertae objects: general – galaxies: jets – galaxies: photometry – quasars: emission lines – quasars: general.

## 1 INTRODUCTION

The presence of prominent broad emission lines in the optical/UV spectrum is a hallmark of the Active Galactic Nuclei (AGN) designated as quasars. However, such lines can appear much weaker for a class of AGN, called blazars, in which the optical/UV emission is dominated by the Doppler boosted nonthermal continuum from the relativistic jet and is therefore substantially polarized. Specifically, this ‘weak line’ characterization holds for a subclass of blazars, called BL Lac objects (BLOs), in contrast to the other blazar subclass, called ‘highly polarized quasars’ (HPQs) which display the emission lines at a fairly strong level (e.g., Urry & Padovani 1995, and references therein). Being jet dominated, both blazar subclasses, HPQs and BLOs are radio loud in the sense that the radio-to-optical flux den-

sity ratio  $R > 10$ , where the radio and optical continuum flux densities refer to the rest-frame wavelengths of 6 cm and 2500Å, respectively (e.g., Kellermann et al. 1989; Stocke et al. 1992). But, whereas HPQs have an abundant population of weakly polarized, radio-quiet counterparts (radio-quiet quasars: RQQs), the existence of radio-quiet analogs of BLOs (RQBLOs) continues to be an open question.

The large optical survey SDSS (York et al. 2000) was used by Collinge et al. (2005) and Anderson et al. (2007) to find candidates for radio-quiet BLOs. They termed such candidates “Weak-Lines-Quasars” (WLQs). In this way, dozens of WLQs marked by abnormally weak broad emission-lines (i.e, rest-frame  $EW < 15.4\text{\AA}$  for the Ly+NV emission-line complex, Diamond-Stanic et al. 2009) have been reported in the literature as summarized in our first paper of this series (Gopal-Krishna, Joshi, & Chand 2013, hereafter Paper I). Since many of the WLQs are indeed found to be radio-quiet (e.g., Plotkin et al. 2010a), they could po-

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tentially qualify as the elusive RQBLOs. However, they are generally regarded as weak-lined analogs of RQQs because, in contrast to BLOs (and much like RQQs), RQWLQs exhibit low optical polarization (Smith et al. 2007) and mild optical continuum variability on time scales ranging from days to years (Plotkin et al. 2010b). This is further corroborated by the similarity observed between the UV-optical spectral indices,  $\alpha$ , of WLQs and RQQs. For RQQs the median value of  $\alpha$  is  $-0.52$  as against  $-1.15$  for BLO candidates (Diamond-Stanic et al. 2009; Plotkin et al. 2010a).

Clearly, the above interpretation of RQWLQs does allow for the possibility that a small subset of them may indeed be the long-sought RQBLOs where the optical continuum is significantly, if not predominantly, contributed by a Doppler boosted relativistic jet. A potentially fruitful approach to explore this possibility was employed in Paper I, where we reported the first search for intranight optical variability (INOV) of RQWLQs. This was motivated by the well established result that BLOs exhibit a distinctly stronger INOV, both in amplitude ( $\psi$ ) and duty cycle (DC), as compared to quasars, specially their more abundant subset, the RQQs (e.g., Gopal-Krishna et al. 2003; Carini et al. 2003; Stalin et al. 2004a; Gupta & Joshi 2005; Carini et al. 2007; Goyal et al. 2012). It is thus evident that INOV behaviour can be a powerful discriminator between blazars and other powerful AGN, both radio-loud and radio-quiet (e.g., Carini et al. 2003; Stalin et al. 2004a; Goyal et al. 2012, 2013). This point is discussed in Paper I and also in Sect. 4 below.

To pursue the above clue, we extracted from the literature a well-defined sample of 18 RQWLQs suited for our intranight optical monitoring (Paper I). The sample was derived from the list of 86 radio-quiet WLQs published in Table 6 of Plotkin et al. (2010a), based on the SDSS Data Release 7 (DR-7, Abazajian et al. 2009). Out of that list, we included in our sample all 18 objects brighter than  $R \sim 18.5$  which are classified as ‘high-confidence’ BL Lac candidate based on their optical spectra. INOV observations of 8 of the 18 RQWLQs were reported in Paper I; these were carried out in 13 sessions mainly with the 130-cm Devasthal Fast Optical Telescope (DFOT) of the Aryabhata Research Institute of observational sciences (ARIES). As part of the same continuing program, we report here 16 sessions of INOV observations of 10 RQWLQs with DFOT.

This paper is organized as follows. Section 2 describes the observations and data reduction, while Section 3 gives details of our statistical analysis. A brief discussion of our results is presented in Section 4.

## 2 DATA SAMPLE AND OBSERVATIONS

The present set of 10 RQWLQs listed in Table 1, was derived from the parent sample of 18 RQWLQs mentioned above. The selection threshold criteria of  $R \sim 18.5$  was adopted for the sample so that 1-2m class telescopes would enable us to obtain a good enough signal-to-noise ratio (SNR) for detecting fluctuations of  $\sim 0.05$  mag with a reasonably good time resolution of  $\sim 10$  minutes, or better. In Paper I, we reported 13 sessions of intranight monitoring of 8 of these 18 RQWLQs. Here we have enlarged this study by monitoring 10 RQWLQs (Table 1)

**Table 1.** The 10 RQWLQs studied in the present work.

IAU Name <sup>a</sup>	R.A.(J2000) (h m s)	Dec(J2000) ( $^{\circ}$ ' ")	$R$ (mag)	$z$
(1)	(2)	(3)	(4)	(5)
J081250.79+522531.05*	08 12 50.80	+52 25 31	18.30	1.152
J084424.20+124546.00*	08 44 24.20	+12 45 46	18.28	2.466
J090843.25+285229.80	09 08 43.25	+28 52 29	18.55	0.930
J101353.45+492757.99	10 13 53.45	+49 27 57	18.40	1.635
J110938.50+373611.60	11 09 38.50	+37 36 11	18.72	0.397
J111401.31+222211.50	11 14 01.31	+22 22 11	18.77	2.121
J115637.02+184856.50	11 56 37.02	+18 48 56	18.42	1.956
J121929.50+471522.00*	12 19 29.50	+47 15 22	17.66	1.336
J212416.05-074129.90	21 24 16.05	+07 41 29	18.29	1.402
J224749.56+134250.00	22 47 49.56	+13 42 50	18.53	1.179

<sup>a</sup> Sources marked by \* were also reported in Paper I.

in 16 sessions; among them 7 RQWLQs being newly observed and three are repeated from our sample in Paper I (namely, J081250.79+522531.05, J084424.20+124546.00, J121929.50+471522.00). This has led to an enlarged dataset of 29 sessions covering 15 RQWLQs, as discussed in Sect. 4.

### 2.1 Photometric Observations

Intranight monitoring for  $\gtrsim 3.5$  hours of each RQWLQs was carried out using the 130-cm DFOT of ARIES, located at Devasthal, India (Sagar et al. 2011). It is a fast beam (f/4) optical telescope with a pointing accuracy better than 10 arcsec RMS. DFOT is equipped with a  $2K \times 2K$  Peltier-cooled Andor CCD camera having a pixel size of 13.5 micron and with a plate scale of 0.54 arcsec per pixel. The CCD covers a field of view of 18 arcmin on the sky. The CCD is read out with 31 and 1000 kHz speeds, with the corresponding system RMS noise of 2.5, 7 e- and gain of 0.7, 2 e-/Analog to Digital Unit (ADU). The CCD used in our observation was cooled thermo-electrically to  $-85$  degC. We observed each science frame for about 5–7 minute, to achieve typical SNR better than 25–30. The typical seeing FWHM during our monitoring sessions was 2-2.5 arcsec.

In our sample selection, care was taken to ensure the availability of at least two, but usually more, comparison stars covered within the CCD frame and also within  $\sim 1$  mag of the target RQWLQ. This allowed a reliable differential photometry by identifying and discounting any comparison star(s) found to vary during the monitoring session.

### 2.2 Data Reduction

The raw photometric data were processed using the standard tasks in the Image Reduction and Analysis Facility IRAF<sup>1</sup>. For pre-processing of an image, we generated a master bias frame by taking the median of all the bias frames and then subtracted it from all the flat and source images. Master flat was generated by taking the median of all the flat frames and then normalising the master flat. Each source image was then flat-fielded by dividing by the normalised master flat, in order to remove pixel-to-pixel inhomogeneities.

<sup>1</sup> IMAGE REDUCTION AND ANALYSIS FACILITY  
([HTTP://IRAF.NOAO.EDU/](http://iraf.noao.edu/))

Finally, cosmic-ray removal was carried out from all source frames using the IRAF task *cosmicrays*. The instrumental magnitudes of the target and the comparison stars in the image frames were determined by aperture photometry (Stetson 1992, 1987) and using the Dominion Astronomical Observatory Photometry software II (DAOPHOT II). For the aperture photometry, we used four aperture radii,  $1 \times \text{FWHM}$ ,  $2 \times \text{FWHM}$ ,  $3 \times \text{FWHM}$  and  $4 \times \text{FWHM}$ . Seeing disk radius ( $=\text{FWHM}/2$ ) for each CCD frame was determined by taking the mean value found for 5 fairly bright unsaturated stars in each frame. The data reduced with different aperture radii were found to be in good agreement. But the best SNR was almost always found with aperture radius of  $2 \times \text{FWHM}$ , so we adopted it for our final analysis.

To derive the Differential Light Curves (DLCs) of a given RQWLQ monitored in a session, we selected two steady comparison stars present within the CCD frames, on the basis of their proximity to the target RQWLQ, both in location and magnitude. Coordinates of the comparison star pair selected for each RQWLQ are given in Table 2. The  $g-r$  color difference for our ‘quasar-star’ and ‘star-star’ pairs is always  $< 1.6$  mag, with a median value of 0.7 (column 7, Table 2). Detailed analyses by Carini et al. (1992) and Stalin et al. (2004a) show that a color difference of this magnitude should produce negligible effect on the DLCs as the atmospheric attenuation changes during a monitoring session.

Since the selected comparison stars are non-varying, as judged from the steadiness of their DLCs, any sharp fluctuation over a single temporal bin was taken to arise due to improper removal of cosmic rays, or some unknown instrumental effect, and such outlier data points (deviating by more than  $3\sigma$  from the mean) were removed from the affected DLCs, by applying a mean clip algorithm. In practice, such outliers were quite rare and never exceeded two data points for any DLCs, as displayed in Figures 1,2.

### 3 STATISTICAL ANALYSIS

Until a few years ago the most commonly used criterion for testing the presence of INOV is based on the so-called C-statistics, which is defined as the ratio of standard deviations of the QSO-star DLC and the corresponding star-star DLC (e.g., Jang & Miller 1997). Recently, de Diego (2010) has emphasised that the usual definition of C-test is not a proper statistic, being based on the ratio of standard deviations which (unlike the ratio of variances) is not a linear statistical operator. They advocated more powerful statistical tests, namely, the one-way analysis of variance (ANOVA) and the F-test. However, a proper use of the ANOVA test requires a rather large number of data points in the DLC, so as to have several points within each subgroup used for the analysis. This is not feasible for our DLCs since they typically have only around 25 - 50 data points each. Therefore, in this study we shall rely on the F-test which is based on the ratio of variances,  $F = \text{variance}(\text{observed})/\text{variance}(\text{expected})$  (de Diego 2010). There are two versions of this test in the literature : (i) the standard  $F$ -test (hereafter,  $F^\eta$ -test, Goyal et al. 2012) and (ii) scaled  $F$ -test (hereafter,  $F^\kappa$ -test, Joshi et al. 2011). The latter test is more relevant in the cases where

magnitudes of the comparison stars are quite different from that of the target AGN (Joshi et al. 2011). However for all our RQWLQs, we could find comparison star within one magnitude of the RQWLQ monitored. Therefore, we have applied the  $F^\eta$ -test to our DLCs. Additionally, in view of recent detailed work by Goyal et al. (2013, hereafter GG-WSS13) the  $F^\eta$ -test offers an additional advantage, since our INOV results for RQWLQs can be directly compared with the results published recently by GGWSS13 based on the application of the  $F^\eta$ -test to the INOV observations of several prominent classes of powerful AGN, taken in 262 monitoring sessions.

Before applying the  $F^\eta$ -test, we recall here that the photometric errors, as returned by the routines in the data reduction softwares (IRAF and DAOPHOT), are normally underestimated by a factor  $\eta$  ranging between 1.3 and 1.75, as estimated in different studies (e.g., Gopal-Krishna et al. 1995; Garcia et al. 1999; Sagar et al. 2004; Stalin et al. 2004b; Bachev et al. 2005). In a recent analysis by Goyal et al. (2012), the best-fit value of  $\eta$  was estimated to be 1.5. Following them,  $F^\eta$ -test can be expressed as :

$$F_1^\eta = \frac{\text{var}(q-s1)}{\eta^2 \langle \sigma_{q-s1}^2 \rangle}, F_2^\eta = \frac{\text{var}(q-s2)}{\eta^2 \langle \sigma_{q-s2}^2 \rangle}, F_{s1-s2}^\eta = \frac{\text{var}(s1-s2)}{\eta^2 \langle \sigma_{s1-s2}^2 \rangle} \quad (1)$$

where  $\text{var}(q-s1)$ ,  $\text{var}(q-s2)$  and  $\text{var}(s1-s2)$  are the variances of the ‘quasar-star1’, ‘quasar-star2’ and ‘star1-star2’ DLCs and  $\langle \sigma_{q-s1}^2 \rangle = \sum_{i=1}^N \sigma_{i,err}^2(q-s1)/N$ ,  $\langle \sigma_{q-s2}^2 \rangle$  and  $\langle \sigma_{s1-s2}^2 \rangle$  are the mean square (formal) rms errors of the individual data points in the ‘quasar-star1’, ‘quasar-star2’ and ‘star1-star2’ DLCs, respectively. The scaling factor  $\eta = 1.5$ , as mentioned above.

The  $F^\eta$ -test is applied by computing the  $F$  values for individual DLCs, using Eq. 1, and then comparing each computed value with the critical  $F$  value,  $F_{\nu_{qs}, \nu_{qs}}^{(\alpha)}$ , where  $\alpha$  is the significance level set for the test, and  $\nu_{qs}$  is the degrees of freedom of the given ‘quasar-star’ DLC. Here, we used two significance levels,  $\alpha = 0.01$  and  $0.05$ , which correspond to confidence levels of greater than 99 and 95 per cent, respectively. If  $F$  is found to exceed the critical value, the null hypothesis (i.e., no variability) is discarded at the corresponding level of confidence. Thus, a RQWLQ is marked as *variable* (‘V’), if both its DLCs (relative to the two comparison stars) have  $F\text{-value} \geq F_c(0.99)$ , which corresponds to a confidence level  $\geq 99$  per cent, and *non-variable* (‘NV’) if any one of its two DLCs is found to have  $F\text{-value} \leq F_c(0.95)$ . Any remaining cases are classified as *probably variable* (‘PV’).

The inferred INOV classification for the DLCs of each RQWLQ, drawn relative to two comparison stars, is presented in Table 3. In the first 4 columns, we list the name of the RQWLQ, date of its monitoring, duration of monitoring and the number of data points (N) in the DLCs. The next two column give the computed F-values and the INOV status of the two DLCs of the RQWLQ, as inferred from the  $F^\eta$ -test. Column 7 gives the session-averaged photometric error  $\sigma_{i,err}(q-s)$  for the ‘quasar-star’ DLCs (i.e., mean value for q-s1 and q-s2 DLCs). Typically, it lies between 0.02 and 0.07 mag (without the  $\eta$  scaling mentioned above). The last column gives the peak-to-peak INOV amplitude  $\psi$  based on the definition given by Romero, Cellone, & Combi (1999), as

**Table 2.** Basic parameters and observing dates of the 10 RQWLQs (and their comparison stars).

IAU Name	Date	R.A.(J2000)	Dec.(J2000)	$g$	$r$	$g-r$
(1)	dd.mm.yy	(h m s)	( $^{\circ}$ $'$ $''$ )	(mag)	(mag)	(mag)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
J081250.79+522531.0	12.11.2012	08 12 50.79	+52 25 31.0	18.30	18.05	0.25
S1		08 13 28.04	+52 19 33.2	19.57	18.19	1.38
S2		08 13 52.52	+52 27 01.0	18.99	17.79	1.20
J084424.24+124546.5	13.11.2012	08 44 24.24	+12 45 46.5	18.29	17.91	0.37
S1		08 43 58.88	+12 45 21.3	18.72	17.94	0.78
S2		08 44 49.65	+12 52 13.3	18.54	17.88	0.66
J084424.24+124546.5	04.11.2013	08 44 24.24	+12 45 46.5	18.29	17.91	0.37
S1		08 44 17.37	+12 50 18.3	19.30	17.89	1.41
S2		08 44 39.26	+12 44 54.7	18.25	17.88	0.37
J090843.25+285229.8	09.02.2013	09 08 43.25	+28 52 29.8	18.55	18.50	0.05
S1		09 09 00.06	+28 56 48.4	19.23	18.24	0.99
S2		09 08 23.97	+28 59 27.0	19.82	18.35	1.47
J090843.25+285229.8	10.02.2013	09 08 43.25	+28 52 29.8	18.55	18.50	0.05
S1		09 08 58.83	+28 55 38.9	18.92	17.93	0.99
S2		09 08 27.19	+28 52 20.3	18.16	17.89	0.27
J101353.45+492757.9	01.01.2014	10 13 53.45	+49 27 57.9	18.60	18.40	0.20
S1		10 14 52.86	+49 26 02.5	19.22	18.17	1.05
S2		10 13 23.92	+49 19 50.2	18.82	18.07	0.75
J101353.45+492757.9	02.01.2014	10 13 53.45	+49 27 57.9	18.60	18.40	0.20
S1		10 13 58.83	+49 32 13.2	19.36	18.24	1.12
S2		10 14 22.84	+49 29 08.9	18.69	17.98	0.71
J110938.50+373611.6	10.02.2013	11 09 38.50	+37 36 11.6	18.72	18.37	0.35
S1		11 09 33.03	+37 32 04.3	18.50	17.75	0.75
S2		11 09 42.48	+37 33 31.8	18.36	17.66	0.70
J111401.31+222211.5	09.02.2013	11 14 01.31	+22 22 11.5	18.77	18.38	0.39
S1		11 14 20.88	+22 29 41.2	19.30	18.01	1.29
S2		11 14 32.46	+22 17 36.1	19.28	17.87	1.41
J115637.02+184856.5	15.01.2013	11 56 37.02	+18 48 56.5	18.42	18.19	0.23
S1		11 56 17.79	+18 56 44.5	17.82	17.31	0.51
S2		11 56 02.38	+18 52 47.0	17.67	16.93	0.74
J121929.45+471522.8	14.01.2013	12 19 29.45	+47 15 22.8	17.65	17.53	0.12
S1		12 19 06.03	+47 13 10.8	19.00	17.55	1.45
S2		12 19 22.97	+47 09 31.0	17.93	17.44	0.49
J121929.45+471522.8	13.03.2013	12 19 29.45	+47 15 22.8	17.65	17.53	0.12
S1		12 19 04.06	+47 15 03.1	16.62	15.37	1.25
S2		12 19 22.97	+47 09 11.0	17.93	17.44	0.49
J121929.45+471522.8	08.04.2013	12 19 29.45	+47 15 22.8	17.65	17.53	0.12
S1		12 20 17.33	+47 18 04.4	17.63	17.23	0.40
S2		12 19 05.60	+47 07 36.4	18.61	17.24	1.37
J212416.05-074129.9	12.11.2012	21 24 16.05	-07 41 29.9	18.29	18.02	0.27
S1		21 24 06.74	-07 45 25.2	19.40	17.83	1.57
S2		21 24 36.85	-07 33 09.4	19.29	17.78	1.51
J224749.56+134250	13.11.2012	22 47 49.56	+13 42 50.0	18.53	18.26	0.27
S1		22 47 49.24	+13 47 04.3	19.44	18.30	1.14
S2		22 48 16.29	+13 39 05.8	19.75	18.37	1.38
J224749.56+134250	04.11.2013	22 47 49.56	+13 42 50.0	18.53	18.26	0.27
S1		22 47 27.73	+13 48 12.0	19.71	18.36	1.35
S2		22 48 17.81	+13 36 14.3	19.82	18.37	1.45

$$\psi = \sqrt{(D_{max} - D_{min})^2 - 2\sigma^2} \quad (2)$$

with  $D_{min,max}$  = minimum (maximum) of values observed in the RQWLQ DLC and  $\sigma^2 = \eta^2 \langle \sigma_{q-s}^2 \rangle$ , where,  $\eta$  is taken to be 1.5 (Goyal et al. 2012).

The INOV duty cycle (DC) for our RQWLQ sample was computed using the definition of Romero, Cellone, & Combi (1999), as

$$DC = 100 \frac{\sum_{i=1}^n N_i (1/\Delta t_i)}{\sum_{i=1}^n (1/\Delta t_i)} \text{percent} \quad (3)$$

where  $\Delta t_i = \Delta t_{i,obs}(1+z)^{-1}$  is duration of the monitoring session of a RQWLQ on the  $i^{th}$  night, corrected for its cosmological redshift,  $z$ . Since the duration of the observing session for a given RQWLQ differs from night to night, the computation of DC has been weighted by the actual monitoring duration  $\Delta t_i$  on the  $i^{th}$  night.  $N_i$  was set equal to 1, if INOV was detected (i.e., ‘V’), otherwise  $N_i$  was taken as 0.

## 4 RESULTS AND DISCUSSION

This paper extends our work of Paper I which reported the first systematic investigation of the INOV properties of radio-quiet weak-line quasars (RQWLQs). To the 13 DLCs reported in Paper I, we have added here 16 DLCs of durations  $\gtrsim 3.5$  hours (Table 3), derived for 10 RQWLQs of which three were also included in Paper I. Table 3 presents our INOV results for the 10 RQWLQs. These are based on the  $F^\eta$ -test (Eq. 1) which is a more reliable version of the  $F$ -test (Howell et al. 1988; de Diego 2010), as shown by GGWSS13 who applied it to determine the INOV status of 262 DLCs of 77 AGN representing 6 prominent classes of AGN (see below). These authors adopted  $\eta = 1.5$ , as determined by Goyal et al. (2012) from their analysis of a large set of 262 DLCs of comparison stars. It was also shown by GGWSS13 that the INOV duty cycles determined using the  $F^\eta$ -test are indistinguishable from those found using the ‘modified C-test’, again taking  $\eta = 1.5$ . The  $F^\eta$ -test applied



here to the 16 DLCs of 10 RQWLQs, taking  $\eta = 1.5$ , yielded an INOV duty cycle of 5% which rises to 15% if the single case of ‘probable’ INOV (PV) is included (Table 3). The same result is obtained using the ‘modified C-test’, consistent with the finding by GGWSS13, as mentioned above. In order to ascertain the effect of likely uncertainty in  $\eta$  value, we have repeated the computation of INOV duty cycle for the 10 RQWLQs, taking two extreme values for  $\eta$  ( $=1.3$  and  $1.75$ ) reported in the literature (Goyal et al. 2012, and references therein). The INOV duty cycle computed using these extreme values of  $\eta$  range up to 15% which can be treated as an upper limit.

Next, we have computed the INOV duty cycle for the enlarged sample of 29 DLCs obtained by combining our present INOV observations of 10 RQWLQs with those reported in Paper I. We thus find the INOV duty cycle for the combined set of 15 RQWLQs to be  $\sim 5\%$ , rising to  $\sim 11\%$  if the DLCs classified as ‘probable’ INOV (PV) are included. It is interesting to compare these estimates found here for RQWLQs with those reported by GGWSS13 for several other AGN classes, following an essentially identical observing and analysis procedure. The INOV duty cycle inferred by them (using the  $F^\eta$ -test taking  $\eta = 1.5$ ) is 10%(6%) for radio-quiet quasars (RQQs), 18%(11%) for radio-intermediate quasars (RIQs), 5%(3%) for radio lobe-dominated quasars (LDQs), 17%(10%) for radio core-dominated quasars with low optical polarization (LPCDQs), 43%(38%) for radio core-dominated quasars with high optical polarization (HPCDQs) and 45%(32%) for BL Lac objects (BLOs) (The values inside parentheses refer to the DLCs showing INOV amplitude  $\psi > 3\%$ ). The INOV duty cycle for Seyfert galaxies is reported to lie between 10% and 20%, the higher values being associated with the radio-loud subset (e.g., see Carini et al. 2003). Finally, we note that the apparent similarity of the DC estimates found here for the RQWLQs with the afore-mentioned estimates given in GGWSS13 for RQQs, RIQs, LDQs and LPCDQs is likely to be superficial. This is because, in contrast to the INOV detection threshold,  $\psi_{lim}$ , of 1-2% characteristic of the observations used in GGWSS13,  $\psi_{lim}$  reached in our INOV programme for the RQWLQs is a factor 2-3 higher, essentially because the RQWLQs are typically 1-2 mag fainter compared to the AGN samples covered in GGWSS13. Therefore, the present estimates of INOV duty cycle for the RQWLQs may well have to be revised upwards. A proper comparison has to wait for the availability of about a magnitude more sensitive INOV observations for RQWLQs, compared to those reported here and in Paper I. Such sensitivity matched INOV observations of RQWLQs may well yield substantially higher INOV duty cycles than those estimated here, perhaps approaching the values obtained for HPCDQs or BLOs. Efforts are underway to use larger telescopes for intranight monitoring of RQWLQs.

As of now, our programme has revealed two instances of RQWLQ exhibiting an INOV amplitude  $\psi > 3\%$  in a monitoring session, a level rarely observed in our 2-decade long INOV programme (summarised in GGWSS13), except for BLOs and HPCDQs. The two RQWLQs, J090843.25+285229.8 ( $\psi \sim 31\%$  on 10-02-2013, Table 3) and J121929.45+471522.8 ( $\psi \sim 7\%$  on 26-02-2012, Paper I), are thus the best available candidates for the elusive radio-quiet BLOs and both need to be followed up. Further INOV ob-

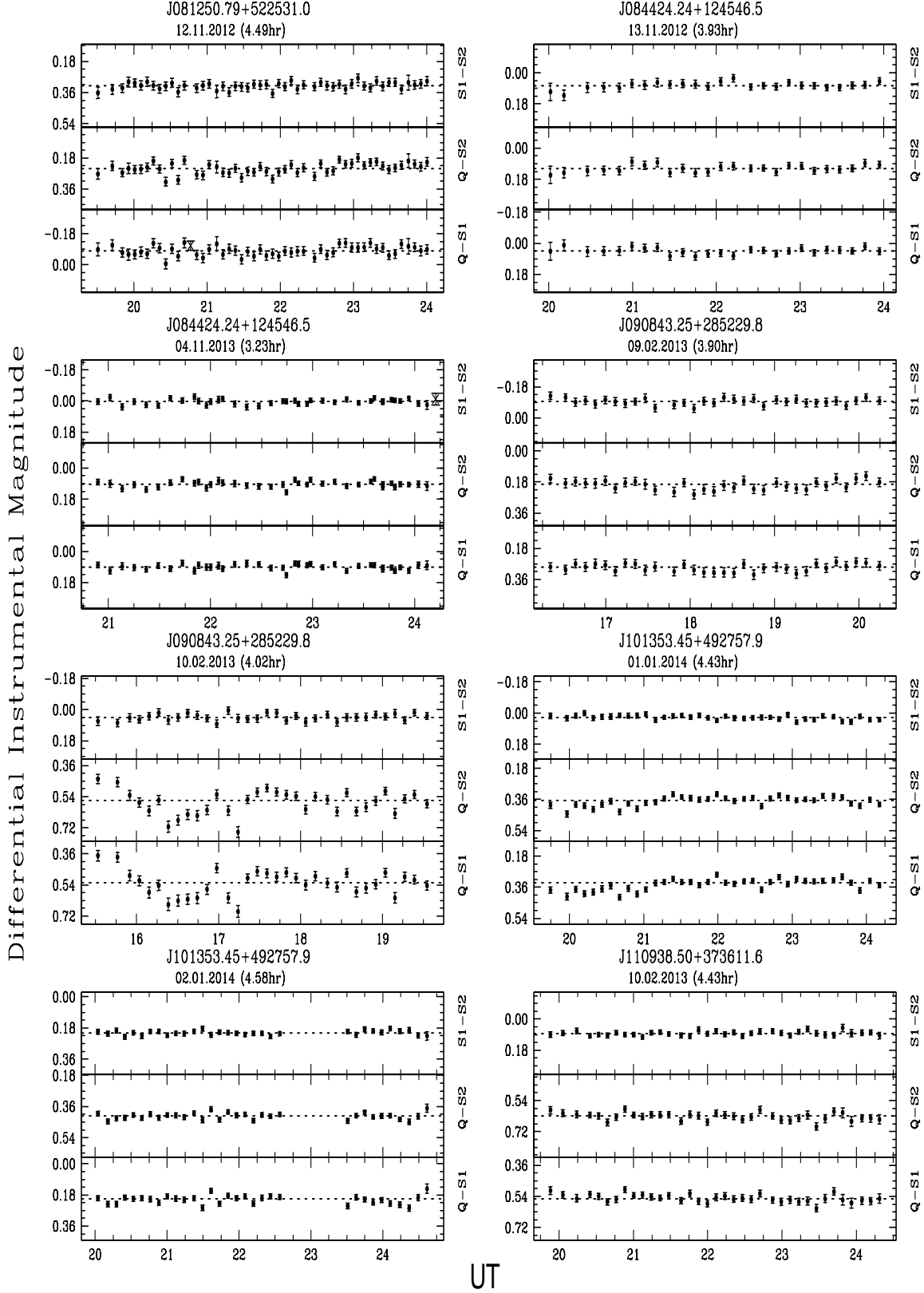
servations of these and several other members of our sample of 18 relatively bright RQWLQs are planned for the next winter months.

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**Figure 1.** Differential light curves (DLCs), for the 10 RQWLQs in our sample. The name of the quasar along with the date and duration of the monitoring session are given at the top of each panel. In each panel the upper DLC is derived using the two non-varying comparison stars, while the lower two DLCs are the ‘quasar-star’ DLCs, as defined in the labels on the right side. Any likely outlier point (at  $> 3\sigma$ ) in the DLCs are marked with crosses and those points are excluded from the statistical analysis.

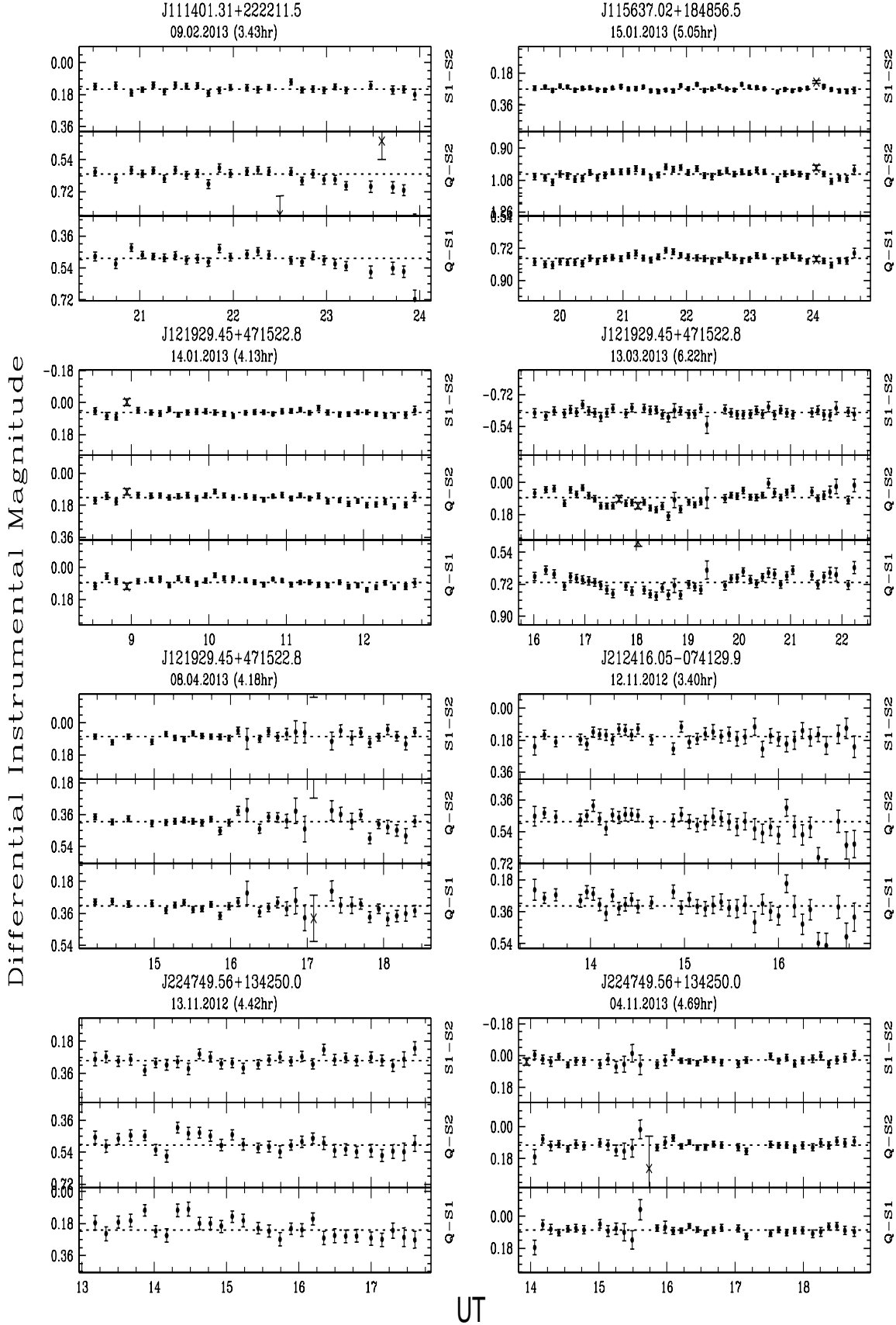


Figure 2. Same as Figure 1, for remaining 8 DLQs.

**Table 3.** Observational details and INOV results for the sample of 10 RQWLQs over 16 monitoring sessions.

RQWLQ	Date	T	N	F-test values	INOV status <sup>a</sup>	$\sqrt{\langle\sigma_{i,err}^2\rangle}$	INOV amplitude
(1)	dd.mm.yyyy	hr	(4)	$F_1^\eta, F_2^\eta$	$F_\eta$ -test	(q-s)	$\psi_1(\%), \psi_2(\%)$
	(2)	(3)		(5)	(6)	(7)	(8)
J081250.79+522531.0	12.11.2012	4.49	50	0.44, 0.78	NV, NV	0.04	10.70, 12.91
J084424.24+124546.5	13.11.2012	3.93	25	0.23, 0.33	NV, NV	0.04	3.91, 5.66
J084424.24+124546.5	04.11.2013	3.23	38	0.45, 0.50	NV, NV	0.02	6.15, 6.95
J090843.25+285229.8	09.02.2013	3.90	32	0.33, 0.44	NV, NV	0.04	5.06, 8.90
J090843.25+285229.8	10.02.2013	4.02	33	3.01, 3.14	V, V	0.04	31.73, 30.20
J101353.45+492757.9	01.01.2014	4.43	37	1.96, 1.58	PV, NV	0.02	12.79, 11.07
J101353.45+492757.9	02.01.2014	4.58	32	1.10, 0.78	NV, NV	0.02	10.68, 7.31
J110938.50+373611.6	10.02.2013	4.43	36	0.54, 0.52	NV, NV	0.03	9.89, 9.14
J111401.31+222211.5	09.02.2013	3.43	25	2.15, 2.80	PV, V	0.04	28.47, 30.43
J115637.02+184856.5	15.01.2013	5.05	41	0.59, 0.74	NV, NV	0.03	7.60, 7.97
J121929.45+471522.8	14.01.2013	4.13	33	0.87, 0.84	NV, NV	0.02	7.54, 7.89
J121929.45+471522.8	13.03.2013	6.22	44	1.30, 1.48	NV, NV	0.04	15.16, 17.86
J121929.45+471522.8	08.04.2013	4.18	30	0.50, 0.59	NV, NV	0.05	14.01, 14.09
J212416.05-074129.9	12.11.2012	3.40	37	1.08, 1.07	NV, NV	0.07	33.33, 35.20
J224749.56+134250.0	13.11.2012	4.42	29	0.89, 0.71	NV, NV	0.05	15.30, 14.32
J224749.56+134250.0	04.11.2013	4.69	35	0.63, 0.45	NV, NV	0.04	20.45, 14.51

<sup>a</sup> V=variable, i.e., confidence level  $\geq 0.99$ ; PV=probable variable, i.e.,  $0.95 - 0.99$  confidence level; NV=non-variable, i.e., confidence level  $< 0.95$ . Variability status values based on quasar-star1 and quasar-star2 pairs are separated by a comma.

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